Institute of Acoustics

A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97
FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE

SUPPLEMENTARY GUIDANCE NOTE 5: POST COMPLETION MEASUREMENTS

ISSUE 1

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PREFACE

This document has been produced by a working group on behalf of the Institute of Acoustics consisting of the following members:

Matthew Cand	Hoare Lea Acoustics
Robert Davis	RD Associates
Chris Jordan	Northern Group Systems (Environmental Health)
Malcolm Hayes	Hayes McKenzie Partnership Ltd.
Richard Perkins	Parsons Brinckerhoff Ltd.

The working group gratefully acknowledges the assistance provided by Andy McKenzie from Hayes McKenzie Partnership Ltd in the drafting of this note.

This supplementary guidance note has been produced to supplement the IOA document 'A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97 FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE' which is available on the IOA website at the following link: http://www.ioa.org.uk/publications/good-practice-guide (checked 06.04.14).

Prior to publication of this note, a peer review was undertaken by a separate group.

Any comments on this document should be sent to ETSUCONSULT@IOA.ORG.UK. The IOA will keep the document under review, and consider updating when significant changes to current good practice have occurred.

Richard Perkins
Working Group Chairman & Editor.

Institute of Acoustics

3rd Floor St Peter's House
45-49 Victoria Street
St. Albans
Hertfordshire
AL1 3WZ
United Kingdom
www.ioa.org.uk

Supplementary Guidance Notes

Number	Title	Information
1	**Data Collection**	Equipment specifications; measurement surveys: Practical considerations and set-up guidance and examples.
2	**Data Processing & Derivation of ETSU-R-97 background curves**	Data filtering, processing and regression analysis for different types of noise environments.
3	**Sound Power Level Data**	Manufacturer's data and warranties analysis.
4	**Wind Shear**	Wind speed references and long-term data analysis.
5	**Post Completion measurements**	Examples, considerations and strategies.
6	**Noise Propagation over water for on-shore wind turbines**	Noise propagation for on – shore turbines, or those close to the shore over large bodies of water.

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1 Context

1.1 Background

1.1.1 The Institute of Acoustics (IOA) published 'A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97 FOR THE ASSESSMENT AND RATING OF WIND TURBINE NOISE' (GPG) in May 2013 to provide technical assistance for the undertaking of wind turbine noise assessments using the ETSU-R-97 document. In order to keep the GPG to a reasonable length, but not to lose clarifications and case studies, it was decided to produce a number of supplementary guidance notes which would support the GPG.

1.1.2 This guidance note will be of relevance to:

i. Acoustics consultants;
ii. Local Planning Authority (LPA) Environmental Health and Planning departments;
iii. Developers;
iv. The Planning Inspectorate or equivalent regulating authority;
v. The general public.

1.2 Scope of the Document

1.2.1 A series of six Supplementary Guidance Notes have been produced. This Supplementary Guidance Note (SGN) 5 supports Section 7.3 of the GPG. It provides additional information on the issue of post completion noise measurements carried out either on a 'voluntary' basis or due to the requirements of planning conditions.

1.3 Statutory Context

1.3.1 This Supplementary Guidance Note has been approved by the IOA Council for use by IOA Members and others involved in the assessment and rating of wind turbine noise using ETSU-R-97. It covers technical matters of an acoustic nature which the IOA-NWG believes represent current good practice.

2 Post Completion Measurements

2.1 Noise Limits in Planning Conditions

2.1.1 Noise limits in planning conditions may be specified in a number of different ways. The most common approach at the time of publication of the Good Practice Guide (GPG) is to specify the limit value at integer wind speeds up to 12 m/s (see discussion on wind speed measurement height at Paragraph 8 below) for a number of sample properties around the site (see GPG Appendix B), usually the ones where baseline noise measurements have been carried out to inform the limits themselves.

2.1.2 Interpretation of the resultant requirements is therefore pretty straightforward except where it is necessary to assign limit values to a property not listed in the Conditions. Sometimes it is specified that these should be taken from the geographically nearest of the listed properties but other conditions may require them to be taken from the property which has the most similar background noise levels to the property in question. In practice this is also likely to be the closest, which may be agreed in most circumstances, but a conservative case approach, if agreement cannot be reached, might be to take the limits as the lowest across all properties for each integer wind speed. In some cases it is specified that limits at listed properties should correspond to the 'simplified' ETSU-R-97 of 35 dB L_{A90} irrespective of background noise. This can have significant practical difficulties in terms of enforcement (see Para 2.4.7 below).

2.1.3 A workable alternative to a table of noise limits is to have a table of background noise levels applying, similarly, to integer wind speeds up to 12 m/s. The limit values can then be inferred from the wording of the Conditions with reference to this table of background noise levels where they take the form X dB[1] L_{A90} or 5 dB above the specified background noise level.

2.1.4 For older sites, or sites where there has been less robust legal or technical input into the Conditions, interpretation of the limits may be less straightforward. It may just be stated that the limits should be X dB L_{A90} or 5 dB above the background noise level, without stating what the background levels are or where they should be taken from. In cases where no background noise data is available it will normally be necessary to carry out such measurements to inform the noise limits and, where turbines are already operational, periods

[1] For the normal ETSU-R-97 limits, X is specified as a value between 35 and 40 for day-time and 43 at night. For a financially involved property it would be 45.

of turbine shut-down will inevitably be required. In all cases where the approach to be taken is not clear, or is ambiguous, the procedure to be followed should be confirmed with the Planning Authority. In some cases it is specified that the background noise levels should be taken from the Environmental Statement or similar. In such cases, tabulated values or equations of the prevailing background noise level curves may not be available and it may be necessary to transcribe the required values from the curves provided.

2.1.5 In some situations, the organisation carrying out post completion noise measurements will be the same as that which carried out the noise assessment accompanying the planning application, including the noise predictions used as its basis. It should be ensured that such work is undertaken by professionally competent organisations bound by a code of conduct. Whilst the Planning Authority may suggest that a different organisation undertake the post completion noise measurements, to prevent any perceived conflict of interest, the IOA is satisfied that its members will abide by its Code of Conduct.

2.1.6 The noise limits will normally apply to turbine noise only, and not to the total measured noise level around the site. They will also normally apply only to noise from the development which is the subject of the planning consent as the operator has no control over noise from any other developments. In cases where the total measured noise level is shown to meet the planning limits, it may be definitively concluded that the turbine noise also meets the noise limits. In such circumstances the results obtained from this process are likely to be different to turbine noise immission levels obtained by prediction and should not be considered to invalidate the compliance checking process. Where the limit values are shown to be exceeded by the total noise level, it will be necessary to determine the level of any other noise in the area, as it varies with wind speed, so that it can be subtracted from the total measured noise level at each wind speed in the manner specified by ETSU-R-97. This 'other' noise may consist of noise from other wind turbine sites.

2.1.7 Application of the noise conditions often requires consideration of conditions prevalent during the complaints, but it is also standard practice to consider downwind conditions because of propagation effects. Downwind conditions can generally be defined for each location as conditions in which the angle between the wind direction and the direct line from any wind turbine to the measurement location considered is no greater than 45 degrees[2]. For very large or extended wind farms, it may not always be relevant to consider downwind directions from all wind turbines, and instead consider the turbines primarily contributing to receptor noise levels (or 'primary turbines'). It is suggested that these are determined such that the predicted difference between noise immission levels with all turbines operating and the primary turbines operating be less than 0.5 dB and that this is determined separately for each survey location.

2.2 Measurement of Wind Speed

2.2.1 It should be established whether the limit values, or background noise values, are referenced to wind speed at 10 metres height or at standardised 10 metre height wind speed. This is discussed in the GPG at Section 2.6. Ambiguity may arise where limits are stated to be referenced to 10 metre height wind which elsewhere in the documentation is noted to be obtained from hub height or other height converted to 10 metres height using a specified value of ground roughness or wind shear exponent. These two methods for wind speed height conversion (wind shear or ground roughness) are both described in Annex A of the GPG. In such cases agreement will need to be reached with the relevant planning authority as to the approach to be taken.

2.2.2 Because of the dependency of the noise limits on wind speed, any noise measurements which are carried out to determine compliance will need to be synchronised to wind speed measurements on the site[3].

2.2.3 If the limits or background noise levels are referenced to wind speed at 10 metres height then wind speed measurements will need to be carried out at 10 metres height unless specific arrangements are made with the Planning Authority. It may not be physically practical to install a 10 metre mast on the site, because of wake effects from the turbines or other siting constraints, or the Planning Authority may want to have a data stream available for their own purposes. In such cases it may be possible to agree a conversion factor based on historical wind shear data whereby wind speeds measured at hub height are converted to 10 metre height values based on wind shear values calculated from historic data from the site provided that sufficient data is available (See SGN 4). Where a 10 metre mast is used, it should be located upwind of the wind farm, in the wind direction of interest so as not to be within the turbulent wake of the wind farm. If a

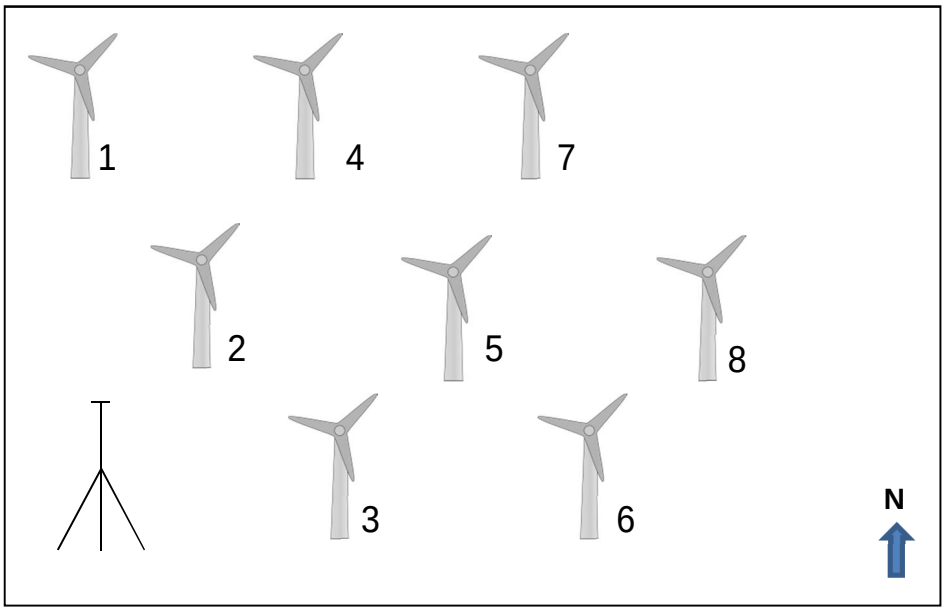
2 As discussed in GPG section 4.4, downwind propagation may effectively occur for a wider arc of wind directions but the proposed 90 degrees arc will generally be suitable in the context of the present SGN.

3 Theoretically this should be measured at the same position as for wind speeds used to inform the baseline measurements but this is often not possible in practice.

number of wind directions are of interest, agreement should be sought with the Planning Authority as to the siting of the mast/s.

2.2.4 Unless wind speed measurements at 10 metres are required as discussed above, data will normally be taken at hub height. This is preferably taken from a permanent on-site anemometry mast, if available. The permanent met mast should be located upwind of the turbines for the prevailing wind direction, so as not to be affected by turbine wake for the majority of time.

2.2.5 Alternatively, data may be obtained from power output from turbines converted to wind speed using the standard power curve for the turbines (Section 8.2 of ES EN 61400-11:2013) although problems arise with this approach above rated power output when the power output no longer increases with wind speed. In utilising turbine power output data as a proxy for wind speed, consideration should be given to the wind direction of interest and hence which turbine to reference i.e. within the diagram below, if the wind direction of interest was South Westerly then turbine 1,2 or 3 would be the reference turbine, whilst if the wind direction of interest was Northerly then turbine 1, 4 or 7 would be the reference turbine.



2.2.6 The use of data from SoDAR or LiDAR remote monitoring systems is discussed at Paragraph 2.6.12 in the GPG and is an alternative method of measuring wind speed post installation. The disadvantage of SoDAR or LiDAR is that this is not normally appropriate for permanent installation at the site which, as for the 10 metre mast discussed above, removes the availability of a continuous data stream which may need to be provided to the planning authority to inform their own measurements or to enable the planning authority to determine the conditions in which complaints arise.

2.2.7 The least preferable method, and only if all other options have been explored, is the use of data from the nacelle mounted anemometers averaged or otherwise processed to provide the necessary wind speed data. Errors can be introduced due to unknown correction for passing blades, influence of the nacelle on the wind flow measured by the anemometer and lack of calibration of nacelle anemometer further to installations etc. If nacelle anemometer data is used it is essential that this is corrected to allow for the effect of the rotating blades in front of the anemometer. This correction should be provided by the manufacturer or incorporated into the data from the turbine control systems. Where it is necessary to shut turbines down for establishing the level of competing noise in verifying compliance with the limits (see Paragraph 2.4.74 below), it should be ensured that the nacelle anemometers, if used, continue to provide a meaningful indication of wind speed whilst the rotors are not moving. This may not be possible for some turbine designs if the turbine is yawed to face the wind as for normal operation under which conditions a stationary turbine blade may significantly shield the anemometer providing less than meaningful results. In all cases it must be ensured that the correction for rotating blades is removed from the wind speed data when the turbine is shut-down. The issue

of wind speed measurements for post completion tests is discussed by Broneske in a paper for Wind Turbine Noise 2013 in Denver[4].

2.3 Measurement Locations and Instrumentation

2.3.1 Whether measurements are carried out voluntarily, or in response to a complaint or otherwise, it is preferable to agree precise monitoring locations with the planning authority as is normally done for the baseline measurements used to inform the limits. Page 84 of ETSU-R-97 states, *"In order to ensure that measurements of wind turbine noise are not influenced by reflections off buildings the microphone should be positioned at least 10m away from the façade."*

2.3.2 In choosing these locations, very similar provisos apply as for the baseline measurements which are discussed in the GPG at Section 2.5 (limit extraneous noise sources) but taking into account the difference between wanting to quantify worst case (i.e. typical highest) turbine noise level rather than worst case (i.e. typical lowest) background noise level. The usual caveats about minimising the contribution from extraneous noise sources and reflections continue to apply and the noise measurement equipment should be in line with the same specifications.

2.3.3 Given the lack of instrumentation with built-in software to cover analysis of any tonal noise to the ETSU-R-97 requirements, wherever such tonal noise assessment is required[5] it will be necessary to carry out audio recordings to be stored in the meter, or similar, for post-processing. The recordings should be of sufficient bandwidth to allow the appropriate analysis to be carried out and should be of a lossless format which means not incorporating any memory saving compression such as MPEG Layer 3 or similar coding. The ETSU-R-97 tonal assessment methodology is constructed around the use of 2 minute audio samples in every 10 minutes of measurement. As the tonal assessment is conducted on an audio sample, more care is needed in terms of excluding transitory sources that would be unlikely to affect the L_{A90} data, but which may corrupt the tonal assessment.

2.3.4 Irrespective of the requirement to carry out tonal analysis, it may be useful to carry out audio recordings for 2 minute samples in every 10 minute interval in all cases to allow for subjective evaluation of any noise effects and particularly of any time histories produced to assist with any discussions about the acoustic character of the noise. Care should be taken during subjective assessment of audio recordings as the subjective prominence of a tone in collected audio may be quite different to that encountered on site due to the limitations of the audio playback system, It should be noted that a subjective assessment of this nature would normally be carried out with regard to a diary of complaints or certain wind conditions that have been found to correlate with complaints since listening to all data would usually be impractical.

2.3.5 Rainfall should be measured when investigating a complaint. Data from such measurements should be made in 10 minute intervals synchronised with the noise, wind and operational data as per Chapter 3 of the Good Practice Guide.

2.4 Noise Data and Data Processing

2.4.1 It will usually be necessary to carry out noise monitoring for around 1 month to obtain the necessary range of wind speeds and wind directions to enable a conclusive evaluation of whether noise limits are being met for worst case downwind propagation conditions or other wind directions as required (see below). The geographical relationship between the site and some properties may mean that downwind conditions are only rarely experienced and extended periods of noise monitoring may be necessary.

2.4.2 As for the baseline measurements required for derivation of the noise limits, measurements of turbine noise should be carried out in 10-minute intervals synchronised with wind speed, direction and other operational data from the site. Noise measurements should be referenced to 'local' time – i.e. GMT or BST as appropriate. Data from the site, including wind data, may be referenced to a different time base; sometimes GMT but also Central European Time is used where the data is supplied through the turbine manufacturer's control systems base in continental Europe. It should also be ensured that the time stamps on both sets of data are the same; i.e. start or end times for each 10 minute period (see also Section 2.8 of the GPG).

4 Broneske, S. "Wind turbine noise measurements - How are results influenced by different methods of deriving wind speed?". 5th International Conference on Wind Turbine Noise, Denver 2013

5 Some planning conditions only require tonal content to be assessed if it is judged by the planning authority, or sometimes the wind farm operator, to be a contributor to the complaint which is being evaluated.

2.4.3 Instrumentation should be within its laboratory calibration period and should be field calibrated prior to commencement of measurements and at any other site visits in the normal way.

2.4.4 Once the survey is complete, or at interim points over the survey period, data analysis can be carried out as follows.

- The relationship between noise, operational and met data is determined.
- Filter out any periods where some but not all of the turbines were shut-down or less than fully operational[6]. Where all turbines were shut-down, as used for the purposes of derivation of the prevailing shut-down noise level (see below), this data would be filtered out from the 'operational' noise data but would be used for deriving noise levels without the wind farm operating.
- Filter out any periods when rainfall may have affected the results (see SGN2).
- Unless there is any particular requirement to measure day-time noise levels (i.e. complaint during these periods) it may be useful to filter out all data except that measured between 2300 and 0400 when competing noise (including early morning birdsong and traffic) would be at a minimum. Evening measurements may also be sufficiently unaffected by spurious sources, depending on the background noise character of the locality.

2.4.5 Measurements should be undertaken in downwind conditions unless there is a specific requirement to measure in other wind directions (i.e. complaint during cross wind conditions), all data except that corresponding to such conditions should be filtered out. At some sites, however, particularly those spread over a large area or partially surrounding a property, it may not be clear what the worst case downwind condition is, in which case it may be necessary to evaluate noise from each directional sector separately.

2.4.6 It is envisaged in the structure of the sample planning condition included at Annex B of the GPG that measurements are first carried out without any turbine shut-downs and that such shut-downs are only required if necessary to demonstrate compliance with the limits. In practice, however, it may be preferable to include shut-downs as routine from the start of the measurements, as this may speed up compliance determination.

2.4.7 When they are carried out, it is useful to programme automatic shut-downs for an hour period per night, preferably at variable times to minimise any particular time-dependent effects, to commence before the start of the intended hour and for normal operation to resume a short time after the end of the period to ensure that full hour of shut-down data is acquired. It may reduce the effect on power output if the shut-down can be targeted for certain wind conditions corresponding to the wind conditions for which data is required.

2.4.8 Once the data has been filtered as discussed above, the noise data can be plotted against wind speed to show two data sets; one for operational noise (i.e. with turbines operating) and one for shut-down noise (i.e. with no turbines operating).. A best fit curve can then be fitted to each data set, assuming sufficient data is available to satisfy the requirements of the planning condition. The operational noise level and the shut-down noise level can then be taken from the curve for each integer wind speed. The calculated turbine noise level can then be obtained by subtracting the shut-down noise level from the operational noise level in the manner prescribed by ETSU-R-97 at Page 88. It should be noted, however, that where the shut-down noise approaches the operational noise, the level of shut-down noise has an increasing effect on the calculated turbine noise such than when the difference between the two is 3 dB or less, it may no longer be appropriate to use this correction with any degree of accuracy and some other method of determining turbine noise in the presence of high levels of background noise may need to be agreed with the planning authority. In the event that the typical background noise is greater than the turbine noise limit, and if the additional contribution of the turbine noise to the prevailing background is difficult to discern with confidence from the data, then it is likely that compliance with the ETSU-R-97 limits would be demonstrated. In such cases where noise limits are less than ETSU-R-97 limits (e.g. apportionment of noise impacts due to cumulative impacts) compliance measurements may need to be undertaken in closer proximity to the wind farm to ensure background noise levels do not unduly influence the readings. This may also be significant when determining compliance with planning limits such as the ETSU-R-97 simplified limit of 35 dB L_{A90} since

6 Fully operational would normally mean all turbines operating unrestricted unless mitigation has been put in place to meet the noise limits, in which case it means 'normal operation' without any additional restrictions. For very large wind farms, shut downs of turbines at a significant distance from the measurement location are unlikely to have a significant impact on the receptor noise levels. In such cases, as long as the 'primary turbines', as determined as per 2.1.7, remain fully operational during the survey period, this remains a valid means of assessment.

background noise is likely to be around this level or higher when the turbine reaches rated power, except under exceptional conditions.

2.4.9 It is likely that tonal noise assessment, if required, will need to be carried out utilising an automated process due to the complexity of the ETSU-R-97 tonal assessment methodology. Once the tone level of audibility has been calculated for each uncorrupted sample (see Paragraph 2.3.3 above), Guidance Note 3 to the sample planning conditions in the GPG suggests that these can be plotted against wind speed to derive the tone level of audibility, and hence total penalty, for each integer wind speed from a best fit linear regression plot through the data. It is, however, very rare that any tonal noise output would be dependent on wind speed in this way and experience suggest that it should be more helpful to calculate the average tone level for each 1m/s wind speed bin, and to base any tonal penalty on this, rather than averaging across all wind speeds in the absence of any linear relationship between the two as the Guidance Note suggests. It those situations where a clear linear relationship is present, the Guidance Note methodology should take precedence.

2.5 Outcome of Measurement Exercise

2.5.1 Where the results of the measurements, once corrected for other noise and any tonal content, show an exceedance of the permitted noise levels, it will be necessary to formulate a mitigation strategy to reduce turbine noise levels to within the prescribed noise limits. This may require certain turbines to be run in noise reduced modes of operation (or switched off) for the relevant wind speeds and directions if available.

2.5.2 In most cases it will be necessary to repeat the measurements with such mitigation in place to demonstrate compliance with the conditions and for the operator to continue to run the site in this way unless circumstances change.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